AD-A049 328 ILLINOIS UNIV AT CHICAGO CIRCLE COMMUNICATIONS LAB F/G 20/3
DIRECT AND INVERSE SCATTERING FROM PERFECTLY CONDUCTING OBJECTS--ETC(U)
FEB 77 P L USLENGHI AFOSR-72-2263

UNCLASSIFIED AFOSR-TR-77-1299 NL

| OF |
ADA049328

END
DATE FILMED
3-78
DDC

AD A049328

DDC FILE COPY

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: AFOSR-TR-77-1299	2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle): DIRECT AND INVERSE SCATTERING FROM PERFECTLY CONDUCTING OBJECTS.	5. TYPE OF REPORT & PERIOD COVERED: Final report
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): Piergiorgio L. E. Uslenghi	8. CONTRACT OR GRANT NUMBER(s): AFOSR-72-2263
9. PERFORMING ORGANIZATION NAME AND ADDRESS: University of Illinois at Chicago Circle, Communications Lab/Dept of Information Eng, Box 4348, Chicago, IL 60680	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 61102F 2304 A4
11. CONTROLLING OFFICE NAME AND ADDRESS: Air Force Office of Scientific Research/NM, Bolling AFB, DC 20332	12. REPORT DATE: Feb [redacted]77
	13. NUMBER OF PAGES: 22
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): 24 p.	15. SECURITY CLASS. (of this report): UNCLASSIFIED
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

DDC RECEIVED FEB 1 1978 B

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

electromagnetic scattering
radiation
conducting objects

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report contains a summary of the research performed under Grant AFOSR 72-2263, with abstracts of ten refereed papers, three scientific reports and seven symposia presentations. The research is concerned with electromagnetic radiation and scattering from conducting and dielectric objects.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED 409 784

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

COMMUNICATIONS LABORATORY
Department of Information Engineering
University of Illinois at Chicago Circle
Box 4348, Chicago IL 60680, USA

AFOSR-TR- 77 - 1299

Final Scientific Report

Grant AFOSR - 72 - 2263

Program Manager: Dr. Robert N. Buchal/NM

February 1977

Prepared for: Air Force Office of Scientific Research
Air Force Systems Command, U.S. Air Force
Bolling AFB
Washington, D.C. 20332

Prepared by:

Piergiorgio L. E. Uslenghi
Principal Investigator

DDC
RECEIVED
FEB 1 1978
B

Approved for public release; distribution unlimited.

AIR FORCE OFFICE OF SCIENTIFIC RESEARCH (AFSC)
NOTICE OF TRANSMITTAL TO DDC
This technical report has been reviewed and is approved for public release IAW AFR 190-12 (7b).
Distribution is unlimited.
A. D. BLOSE
Technical Information Officer

ACCESSION for
NTIS White Section ☑
DDC Buff Section ☐
UNANNOUNCED ☐
JUSTIFICATION
BY
DISTRIBUTION/AVAILABILITY CODES
Dist. AVAIL. and/or SPECIAL
A

FINAL SCIENTIFIC REPORT

Grant AFOSR-72-2263

I - Summary of Research

The main emphasis of the research performed under this grant has been on theoretical studies of high-frequency diffraction and scattering, with the goal of a better understanding of the applicability of available techniques, such as the geometrical theory of diffraction, to problems of interest to the U.S. Air Force. Although much of the effort has been directed to the scattering by perfect conductors, some work has been done on scattering by a plasma-coated body [4] or by inhomogeneous dielectric lenses [5,14].

Exhaustive, critical reviews of high-frequency techniques have been developed in the article [1] and in the report [11]. Specific studies of scattering by perfectly conducting bodies have been directed to the flat-base circular cone [3], to the finite circular cylinder [16], to the semi-infinite elliptic cylinder [21], and to the behavior of torsional creeping waves on a circular cylinder [15]. Article [3] also contains comparisons of the theoretical predictions with experimental data.

Keller's cone of edge-diffracted rays has been experimentally detected, as described in [2]. This result, which was first presented at the URSI General Assembly in Warsaw, Poland (August 1972), has elicited considerable interest, evidenced by numerous requests to borrow the original slides (for example, it is included on two permanent MIT video tapes of a short course on

principles of radar given at Lincoln Laboratory in October 1973).

A problem which is presently of great important in aerospace systems is the penetration of electromagnetic fields inside a shielding enclosure. Two works have been devoted to it: the development of a simple model for penetration through a gasket or seam joining two metal sheets [8], and the derivation and application of a new integral equation for the transient fields inside a shielding enclosure of arbitrary shape [23].

The above works are concerned with direct scattering. The inverse scattering problem has been considered in the paper [9] where presently available methods are surveyed, and in a detailed study of low-frequency inverse scattering by discrete far-field measurements [10,18].

The emerging research area of integrated optics will probably lead to important applications to Air Force electronic systems in future years. With this consideration in mind, moderate efforts have been devoted to this area of research and two new results have been obtained: a theory has been developed for propagation in triangular dielectric waveguides [20], and a strong-coupling theory has been obtained for rectangular optical waveguides [13,19] that leads to the previously available theory of Miller and Marcatili as a limiting case. This latter work has elicited interest and favorable comments by Stewart E. Miller and his collaborators at Bell Telephone Laboratories.

Finally, several studies have been carried out on problems of radiation from antennas. The possibility of steering the main beam by means of a variable active impedance loading has been

investigated [6]. A pattern synthesis method has been developed for radiating apertures on a cylindrical surface [7]. An improved formulation of radiation from feeds and horns has been given [17]. A preliminary study has been conducted on the transient radiation from spherical and spheroidal antennas, with particular attention to early-time radiation [22]. A report which contains new results on antenna admittance and gap problem, on transient radiation from antennas and on transform properties of radiated fields has been written [12].

A list of grant publications is given below, with related abstracts or summaries. The work performed under this grant includes ten refereed journal articles, three scientific reports, and ten papers presented (7) or to be presented (3) at scientific meetings.

II - Publications

a) - Refereed papers

[1] "Geometrical optics calculation of radar cross sections", Proceedings of the National Electronics Conference, vol. 27, pp. 237-242 (83 refs.); invited paper, Chicago, October 1972. (No abstract). Index terms: electromagnetic scattering, high-frequency methods, radar cross sections.

[2] "Experimental detection of the edge-diffraction cone", Proc. IEEE, vol. 60, no. 11, p. 1448, November 1972. (with T.B.A. Senior).

Abstract: The cone of diffracted rays, which is produced when an optical ray is incident on the edge of a reflecting wedge, is detected by illuminating the edge of a razor blade with a laser beam. All experimentally observed features are in agreement with the predictions of the geometrical theory of diffraction.

[3] "Further studies of backscattering from a finite cone", Radio Science, vol. 8, no. 3, pp. 247-249, March 1973. (with T.B.A. Senior).

Abstract: Certain errors in the second-order contributions to the scattered field derived in an earlier study are pointed out, and the corrected formulas are presented. The results are compared with experimental data, and an explanation is suggested for the remaining small discrepancies.

[4] "Scattering by a plasma-coated cylinder", Alta Frequenza, vol. 42, no. 6, pp. 296-297, June 1973.

Abstract: A solution is found for the scattering of an E-polarized wave by an imperfectly conducting cylinder coated by a thin plasma layer.

[5] "Numerical and asymptotic scattering from two inhomogeneous lenses", Applied Physics, vol. 2, no. 1, pp. 11-14, July 1973 (with S.R. Laxpati).

Abstract: The scattering of a time-harmonic, plane electromagnetic wave by either a Maxwell fish-eye or a metal-like lens is considered. Numerical values of the monostatic cross sections are obtained by evaluating the exact, infinite series solutions of hypergeometric functions of the ${}_2F_1$ type. These results are compared with the high-frequency asymptotic estimates based on either geometrical optics or a modified Watson transformation.

[6] "Antenna beam scanning by active impedance loading", IEEE Trans. on Antennas and Propagation, vol. AP-22, no. 5, pp. 722-723, September 1974 (with N.G. Alexopoulos and G.A. Tadler).

Abstract: The concept of antenna beam steering by variable surface impedance loading is investigated. It is shown, as an example, that if an electric dipole is mounted over a prolate spheroid with a variable surface impedance, then the radiated beam can be scanned

considerably. This is achieved provided that the real part of the surface impedance can obtain both negative and positive values. The possible realization of such a scheme is briefly discussed.

[7] "Synthesis of the antenna pattern for a radiating slot in a metal cylinder", IEEE Trans. Antennas and Propagation, vol. AP-23, no. 1, pp. 28-36, January 1975 (with O. Einarsson and F.B. Sleator).

Abstract: The synthesis of a prescribed far-field pattern by means of a radiating slot in a perfectly conducting, infinite circular cylinder is considered. The narrow circumferential slot and the infinite axial slot are studies in detail. In either case, the problem is to find the distribution of the electromagnetic field in the aperture that yields a radiation pattern which is the best mean-square approximation to a given pattern, under certain constraints.

Various quality factors for cylindrical modes are discussed, and a detailed comparison with the synthesis problem for a planar aperture is performed. It turns out that Rhodes' synthesis method has no equivalent in the cylindrical case, and that the best admissable mean-square approximation to a given pattern may be a very poor approximation in amplitude. However, an iteration scheme is developed in which the phase approximation is sacrificed for the sake of substantially improving the amplitude approximation.

Numerical results based on such a scheme are displayed, for prescribed omnidirectional and sectoral patterns.

[8] "A simple model for electromagnetic field penetration through gaskets and seams", Alta Frequenza, vol. 45, no. 10, pp. 616-620, October 1976.

Abstract: The penetration of electromagnetic radiation through a gasket or seam joining two metal sheets is studied, under certain simplifying assumptions. In particular, it is shown that the transfer impedance is an important and meaningful quantity which has a simple physical interpretation.

[9] "Inverse scattering methods", Alta Frequenza, vol. 45, no. 10, pp. 629-632, October 1976.

Abstract: This is a survey of presently available methods in inverse scattering for electromagnetic fields, with a selected bibliography. The inverse geometric optics method is not discussed; see Keller (1959) and Weiss (1968). The related quantum-mechanical problem is discussed in a large number of articles and books (for example, Faddeyev, 1963; Loeffel, 1968; Sabatier, 1972). A comprehensive discussion of the inverse Sturm-Liouville problem in one dimension is contained in Barcilon (1974). The methods used in geophysical prospecting are based on the theories described in the books by Brekhovskikh (1960) and Wait (1962, 1971); see also the special issue of "Geophysics", February 1971.

[10] "Low-frequency inverse scattering by far-field measurements", accepted for publication in IEEE Trans. Antennas and Propagation.

Abstract: It is shown how to determine the electric and magnetic dipole moments as well as the electric quadrupole tensor of a small metallic object, by means of eleven independent measurements of amplitude and phase of far-field components. An explicit solution is obtained for an array of six sensors in the shape of a Latin cross.

b) - Scientific Reports

[11] "High frequency scattering methods", Report No. AFOSR-TR-72-1281, July 1972 (89 pp., 317 refs.). Also presented at the Third International Course on Computer Electromagnetics, University of Naples, Italy, September 1972.

Abstract: A survey of the principal methods used to obtain the electromagnetic and acoustic scattered fields at high frequencies is presented. After a discussion of the Watson transformation, geometrical and physical optics are applied to a variety of scatterers with different shapes and made of different materials. Further refinements of these methods, such as the geometrical theory of diffraction and the theory of fringe waves, are described and compared with each other. A special section is devoted to the scattering by inhomogeneous media. The accuracy of the methods is discussed, and comparisons are made with numerical and experimental data. Other results which are

often useful in high-frequency scattering are given in the appendixes.

The treatment is expository in nature, but the reader is introduced to several topics of current research interest, and to a few as yet unpublished results. Although the bibliography is necessarily selected, it should enable the interested reader to proceed with applications and with further research.

[12] "Topics in advanced antenna theory", by G. Franceschetti, Communications Laboratory Report 76-2, July 1976 (87 pp.).

Abstract: This report contains new research results in (i) antenna admittance and gap problem, (ii) transient radiation from antennas, and (iii) transform properties of radiated fields.

[13] "Coupling between rectangular optical waveguides", Communications Laboratory Report 76-4, December 1976 (59 pp.) (with A.-G. Kazkaz).

Abstract: A theory is developed for strong coupling between two rectangular optical waveguides, that contains the Miller-Marcatili result as a limiting case. The theory allows for a more accurate design of a directional coupler than was previously possible.

c) - <u>Papers presented at scientific meetings</u>

[14] "Numerical and asymptotic scattering from two inhomogeneous lenses", IEEE International Symposium on Antennas and Propagation,

Williamsburg, Virginia, December 1972. (with S.R. Laxpati).

Abstract: The scattering of a time-harmonic, plane electromagnetic wave by either a Maxwell fish-eye or a metal-like lens of radius a is considered. Numerical values of the monostatic cross sections are obtained for $ka \lesssim 8$ by evaluating the exact, infinite series solutions of hypergeometric functions of the ${}_2F_1$ type. These results are compared with the high-frequency asymptotic estimates based on geometrical optics for the Maxwell fish-eye and on a modified Watson transformation (Uslenghi and Weston, Appl. Sci. Res., 23, 147-163, 1970) for the metal-like lens. It is found that for both lenses the exact cross section oscillates about the average geometric-optics value as ka increases An explanation of this resonance is provided on the basis of the Bremmer series.

Computations based on the exact series solution have also been performed for the total field inside a family of lenses that includes the above two lenses as particular cases. A good qualitative agreement exists with the geometric-optics predictions.

[15] "A study of torsional creeping waves", URSI Fall Meeting, Williamsburg, Virginia, December 1972 (with H. Inada).

Abstract: The field produced by a point or dipole source in the presence of a large cylinder of infinite length is considered. The cylinder is perfectly hard or soft in the scalar case, and perfectly conducting in

the vector case. Both source and observation points are located at an arbitrary distance from the cylinder axis. A modified Watson transformation is applied to the exact solution, and the scattered field is expressed as the sum of the reflected field and creeping waves contributions. The results are compared with those obtained by a direct application of Keller's geometrical theory of diffraction.

[16] "High-frequency electromagnetic scattering from a finite circular cylinder", URSI Symposium on Electromagnetic Wave Theory, London, England, July 1974 (with E.F. Knott and T.B.A. Senior).

Summary: The scattered field produced by a linearly polarized, plane harmonic wave obliquely incident on a solid right circular cylinder of finite length is determined at high frequencies by applying Keller's geometrical theory of diffraction (GTD). The first two terms in the asymptotic expansion of the far field are derived for a metallic cylinder, and are compared with the corresponding expansions for acoustically soft and hard cylinders. Particular attention is devoted to backscattering; in this case, the theoretical predictions are compared with measured data.

The contributions to backscattering of various types of optical rays are considered: singly and doubly diffracted edge rays which are coplanar with the cylinder axis; rays doubly diffracted at two migrating

points on the edge of the illuminated base that are symmetrically located with respect to the plane of incidence; and rays which creep on the cylinder surface and are diffracted at the edge of the shadowed base, forming a caustic in the backscattering direction. This last contribution is quite different from the corresponding one for a finite cone. The migrating rays have been previously introduced in studying the scattering properties of large metal disks and cones [1-3] as well as elliptical plates[4], and have improved the agreement between GTD predictions and experiment. Their contribution is easily calculated by means of an improved form of Keller's edge-diffraction matrix[2,5,6].

An alternate formulation which utilizes the equivalent edge currents developed by Knott and Senior[7] is also introduced. It is especially convenient in dealing with second-order diffraction by a circular edge under general bistatic conditions: the double line integral which represents the diffracted field is asymptotically evaluated by double stationary phase, thus yielding the portion of the far field associated with each optical ray without requiring an explicit determination of the geometrical path of that ray.

For the axial and broadside directions of incidence, some flash points are located on the shadow boundary produced by a frontal edge. The field incident on these flash points is specified by introducing an appropriate transition function, thus removing the

discontinuity which would otherwise occur in the backscattered field when a scattering center becomes shadowed. Furthermore, the matching between axial and wide-angle formulas is achieved by means of Bessel functions and Fresnel integrals for the first- and second-order terms, respectively. The expressions thus obtained are uniformly valid for all directions of incidence.

1. E.F. Knott, T.B.A. Senior, and P.L.E. Uslenghi (1971), "High-frequency backscattering from a metallic disk", Proc. IEE (London), 118, No. 12, 1736-1742.

2. T.B.A. Senior and P.L.E. Uslenghi (1971), "High-frequency backscattering from a finite cone", Radio Science, 6, No. 3, 393-406.

3. T.B.A. Senior and P.L.E. Uslenghi (1973), "Further studies of backscattering from a finite cone", Radio Science, 8, No. 3, 247-249.

4. P.L.E. Uslenghi and S.W. Lee (1974), "High-frequency backscattering from an elliptic metal plate", J. Math. Phys., 15, no 5, 631-639.

5. R.G. Kouyoumjian and P.H. Pathak (1971), "The dyadic coefficient for a perfectly conducting edge structure", URSI Fall Meeting, Los Angeles, California.

6. G.A. Deschamps (1973), "Diffraction of an arbitrary plane electromagnetic wave by a half-plane", IEEE Trans., AP-21, No.1, 126-127.

7. E.F. Knott and T.B.A. Senior (1973), "Equivalent

currents for a ring discontinuity", IEEE Trans., AP-21, No. 5, 693-695.

[17] "Toward a novel formulation of radiation from truncated guiding structures", by G. Franceschetti, National Conference on Electromagnetic Scattering, Chicago, Illinois, June 1976.

Summary: The problem of electromagnetic radiation from truncated guiding structures, as open-ended waveguides and horns, is certainly most important from the application point of view. When the guiding structure is used as a primary radiator of a reflector-type antenna, it would be highly desirable to have reliable expressions for the radiated field in a wide angular region, thus controlling edge illumination of the reflector as well as angular variation of the phase center of the feed. It is obvious that the aperture integration method coupled with Kirkhhoff approximation is a rather unsatisfactory approach to this problem and that other computational techniques should be devised.

It is worth remembering that closed analytical solutions exist for radiation from a limited number of truncated structures: essentially the parallel-plate and the circular waveguide, the latter excited by azimuthally symmetric as well as non-symmetric modes[1]. Also, ray optical techniques have been used rather extensively, either for straight[2-5] or flared waveguides[6-9].

In this note a novel approach is suggested for

computing radiation from truncated guiding structures. The basic idea is to relate radiation to elementary scattering coefficients associated to the incident surface current on the rim of the truncated structure. These coefficients are determined, in turn, by examination of the canonical problem of the open-ended parallel plate waveguide. It is worth emphasizing that this approach is completely different from the equivalent edge current method[10,11] for at least two reasons. First, the surface currents which are taken into account are the effective incident, in principle measurable, ones and their value is independent from the observation angle (an obvious physical contraint which is not met by edge currents). Then, the scattering coefficients just anticipated are computed with reference to a different canonical problem -- the open-ended parallel plate waveguide -- thus taking into account interaction process between the two rims of the plates.

There are two of these scattering coefficients, relative to surface currents incident parallel and perpendicular to the edge respectively. For two parallel facing elements of the guide, each of length dx, and with spacing 2a, the elementary scattered vector potential is given at large distances by

$$dA_{\parallel} = \frac{J_{\parallel} dx}{-i\omega} \frac{\exp(-i\beta r)}{2\pi r} \frac{\cos\theta/2}{\cos\theta_g/2} \frac{\exp(-i\beta r') \pm \exp(-i\beta r'')}{\cos\theta - \cos\theta_g} \cdot$$

$$\cdot I(\theta, \theta_g, \beta a),$$

$$dA_{\perp} = \frac{J_{\perp} dx}{-i\omega} \frac{\exp(-i\beta r)}{2\pi r} \frac{\cos\theta_g/2}{\cos\theta/2} \frac{\exp(-i\beta r') \pm \exp(-i\beta r'')}{\cos\theta - \cos\theta_g}$$

$I(\theta, \theta_g, \beta a)$, where r', r'' are the distances from the two elements respectively, r is the distance from the center of the two elements, $\beta\cos\theta_g$ is the guide propagation constant and the other symbols are self-explanatory. Note that the plus or minus sign should be taken according to equal or opposite direction of surface currents on the two rims, and that $I(\theta, \theta_g, \beta a)$ is the function describing the interaction between the two rims. This, in turn, is given by

$$I(\theta, \theta_g, \beta a) = \exp\left[V^{\pm}\left(\frac{\beta a}{\pi}, \sqrt{\beta a}\cos\theta_g\right) - V^{\pm}\left(\frac{\beta a}{\pi}, \sqrt{\beta a}\cos\theta\right)\right]$$

$$V^{\pm}(p,q) = \frac{1}{2\pi i}\int_{-\infty}^{+\infty} \ln\left[-1 \pm \exp\left(2\pi i p - \frac{t^2}{2}\right)\right] \frac{dt}{t - q\exp(-i\pi/4)}$$

according to Weinstein[1].

Use of the above introduced scattering coefficients allows recovery of the (known) solution of radiation from the circular waveguide, exactly for the azimuthally symmetric modes and up to terms of order $1/\sqrt{\beta a}$ included for the asymmetrical ones. The coefficients can be successfully used for predicting radiation from coaxial cables of circular cross-section and rectangular waveguides. Work is in progress for considering non-parallel guide elements and an eventual flare angle of the guide.

This theory is expected to play an interesting

role in the design of primary feeds whose radiation patterns could be controlled by changing surface currents on the rim of the radiator.

1. Weinstein, L.A., The theory of diffraction and the factorization method, Golem Press, 1969, Chs. 1-4.

2. Lee, H.W., L.B. Felsen, and J.B. Keller, SIAM J. Appl. Math., 16, 268-300, 1968.

3. Boersma, J., SIAM J. Appl. Math., 29, 164-195, 1975.

4. Boersma, J., Proc. IEEE, 62, 1475-1481, 1974.

5. Ryan, C.E., and R.C. Rudduck, IEEE Trans. Antennas and Propag., AP-16, 488-489, 1968.

6. Russo, P.M., R.C. Rudduck, and L. Peters Jr., IEEE Trans. Antennas and Propag., AP-13, 219-224, 1965.

7. Yu, J.S., R.C. Rudduck, and L. Peters, Jr., IEEE Trans. Antennas and Propag., AP-14, 138-149, 1966.

8. Yu, J.S. and R.C. Rudduck, IEEE Trans. Antennas and Propag., AP-17, 651-652, 1969.

9. Mentzer, C.A., L. Peters, Jr., and R.C. Rudduck, IEEE Trans. Antennas and Propag., AP-23, 153-159, 1975.

10. Millar, R.F., Inst. Elec. Eng. Monograph 152R, 1955.

11. Ryan, C.E., and L. Peters, Jr., IEEE Trans. Antennas and Propag., AP-17, 292-299, 1969.

[18] "Inverse multipole scattering by far-field measurements", National Conference on Electromagnetic Scattering, Chicago, Illinois, June 1976.

Summary: The scattering properties of a small object can be investigated by means of far-field measurements of the amplitude and phase of electric or magnetic field components. The measured fields are either directly radiated by the object, or produced by the scattering of a primary wave. In the latter case, the primary fields are subtracted from the measured total fields whenever the sensors are illuminated by the primary wave.

The scattering properties of the object are identified with its electric and magnetic dipole moments and with its six electric quadrupole moments, so that twelve scalar quantities must be determined via independent measurements of far-field components. All twelve quantities can be found, except for the three diagonal elements of the electric quadrupole tensor that are determined only within a common but arbitrary additive constant. This is due to the fact that a quadrupole tensor with equal diagonal elements and zero off-diagonal elements does not radiate[1]. The number of unknowns is therefore reduced to eleven.

Under the hypothesis that only electric and magnetic dipole and electric quadrupole moments contribute to the scattering, it is clear that no more than eleven far-field measurements can be independent of one another.

A discussion on the choice of measurements is performed, and criteria are given to avoid redundancy. The eleven unknowns are found by numerically solving a system of eleven linear equations. An explicit solution is possible only for certain simple choices of the array of sensors. One such choice is discussed in detail: it consists of an array of six sensors arranged in the shape of a Latin cross; two measurements corresponding to perpendicular polarizations of the received electric field are performed at five sensors, but only one measurement at the sixth. Specific examples are worked out in detail.

Although the discussion is confined to a perfectly conducting object for sake of simplicity, it remains valid for a cluster of objects and could be easily extended to scatterers made of arbitrary material. The inclusion of higher-order multipoles would entail cumbersome calculations and additional measurements. For simplicity, one could consider only dipoles as done in the direct case by Keller et al[2]. However, for an elongated metal scatterer, the magnetic dipole and the electric quadrupole moments yield contributions of the same order of magnitude to the far field.

If all eleven measurements are performed simultaneously and fed to a minicomputer, one can follow the variations of the dipole moments and of the electric quadrupole moment of a small flying object or group of objects in real time, and thus draw important conclu-

sions as to the identity of the object. The accuracy of the results depends on the precision with which one can measure the far-field amplitudes and relative phases, the distance of the object from one of the array elements, and the angles between any two elements as seen from the object. While accurate results can be obtained under laboratory conditions, tolerably good ones may be difficult to obtain under field conditions.

1. G.A. Deschamps (1952), Lecture notes on radiation by small antennas, Illinois Institute of Technology (unpublished), Chicago.
2. J.B. Keller, R.E. Kleinman and T.B.A. Senior (1972), "Dipole moments in Rayleigh scattering", J. Inst. Math. Applics., Vol. 9., pp. 14-22.

[19] "Coupling between rectangular optical waveguides", URSI Fall Meeting, Amherst, Massachusetts, October 1976 (with A.-G. Kazkaz).

Abstract: The coupling between two rectangular dielectric waveguides embedded in a dielectric substrate is considered. The boundary-value problem is analyzed in the approximation of Marcatili[1], but the power transfer between the two guides is described by means of a first-order non-linear differential equation. If the linear term is neglected in the differential equation, then the approximation of Miller[2] is obtained. Miller's approximation was previously employed by Marcatili[1] in his analysis of the directional coupler.

The solution of our nonlinear equation, which is

valid for an arbitrary distance between the two guides, shows that the power is transferred back and forth between the guides. Design criteria are developed which yield the minimum coupling length for a pre-assigned percentage of power transfer. In particular, it is shown that 100% power transfer is possible only in the Miller-Marcatili approximation[1-2], which is a limiting case of our more general theory and corresponds to the physically unrealizable situation of an infinite distance between guides and an infinite coupling length.

1. E.A.J. Marcatili, Bell Sys. Tech. J., Sept. 1969, pp. 2071-2102.
2. S.E. Miller, Bell Sys. Tech J., May 1954, pp. 661-719.

[20] "Theory of triangular optical waveguides", URSI Fall Meeting, Amherst, Massachusetts, October 1976 (with Y.-K. Lee).

Abstract: Triangular optical waveguides may be fabricated by preferential etching technique on crystalline substrates[1,2], as demonstrated in at least two different ways: a guide made of polyurethan (refractive index n = 1.56) on a silicon substrate (n = 3.5) with a separating layer of SiO_2 (n = 1.45) approximately one micron thick[3], and a guide of gallium arsenide (n = 3.6) on a GaAs substrate with a separating layer of $Ga_{1-x}Al_xAs$ ($n \approx 3.4$)[4]. In both cases, the guide cross-section is

an isosceles triangle.

Light propagation in triangular waveguides is examined by an extension of Marcatili's analysis of the rectangular waveguide. A ray-tracing interpretation of the modal description is performed. Rough estimates of the cutoff frequencies for the various modes are given, and design criteria to allow for single-mode propagation are developed.

1. R.M. Finne and D.L. Klein, J. Electrochem. Soc.: Solid State Science, 114, 965-970 (September 1967).

2. S. Iida and K. Ito, J. Electrochem. Soc.: Solid State Science, 118, 5, 768-771 (May 1971).

3. C.-C. Tseng, D. Botez and S. Wang, Appl. Phys. Letters, 26, 12, 699-701 (June 15, 1975).

4. W.T. Tsang and S. Wang, Appl. Phys Letters, 28, 11, 665-667 (June 1, 1976).

The following three papers are being prepared for presentation at the URSI Symposium on Electromagnetic Wave Theory and AP International Symposium, Stanford University, Palo Alto, California, June 1977:

[21] "High-frequency backscattering from an elliptic semi-infinite cylinder", (with C.A. Chang).

[22] "Transient radiation from a spheroidal antenna", (with J.D. Kotulski and G. Franceschetti).

[23] "Fundamentals of transient electromagnetic fields inside a shielding enclosure", by G. Franceschetti.